ISSN 1413-3555
Rev Bras Fisioter, São Carlos, v. 15, n. 3, p. 206-11, May/June 2011




# Muscular activity of patella and hip stabilizers of healthy subjects during squat exercises

## Ativação muscular dos estabilizadores da patela e do quadril durante exercícios de agachamento em indivíduos saudáveis

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## Abstract

**Background:** Hip and knee muscle weaknesses have been associated with the onset of anterior knee pain (AKP). Therefore, the understanding of how squats exercises can be performed in order to optimize the electrical activity of these muscles is relevant for physical therapy treatments. **Objective:** To compare the electromyographic activity of patella and pelvic stabilizers during traditional squat and squat associated with isometric hip adduction or abduction in subjects without AKP. **Methods:** Electromyography signals were captured using double-differential electrodes at the *vastus medialis obliquus* (VMO), *vastus lateralis obliquus* (VLO), *vastus lateralis longus* (VLL) and *gluteus medium* (GMed) in 15 healthy and sedentary women during squats exercises: traditional and associated with hip adduction and hip abduction with load of 25% of body weight. Linear mixed models with significance level of 5% were used for data analysis. **Results:** Squat associated with hip adduction and abduction produced electromyographic activity of GMed of 0.47 (0.2) and 0.59 (0.22) respectively, while conventional squat produced an electromyiographic activity of 0.33 (0.27). The higher VMO activity was 0.59 (0.27) during the isometric contraction in the squat associated with hip adduction. The higher VLO activity was 0.60 (0.32) during isometric contraction in the squat associated with hip abduction. **Conclusion:** Squat exercise associated with hip adduction increased VMO muscle activity as well as the activity of GMed activity.

**Keywords:** exercise therapy; kinesiology; electromyography; knee; hip.

## Resumo

**Contextualização:** Atualmente relaciona-se a fraqueza dos músculos do quadril e da coxa ao surgimento da dor anterior no joelho (DAJ). Dessa maneira, compreender como os agachamentos devem ser realizados para melhorar a ativação elétrica desses músculos é importante para o tratamento fisioterapêutico. **Objetivo:** Comparar a ativação dos estabilizadores da patela e pelve entre as posições de agachamento convencional e associado à contração isométrica em adução e abdução da coxa em indivíduos sem queixa de DAJ. **Métodos:** O sinal eletromiográfico foi captado a partir de eletrodos duplo-diferenciais posicionados nos músculos vasto medial oblíquo (VMO), vasto lateral oblíquo (VLO), vasto lateral longo (VLL) e glúteo médio (GMed) em 15 mulheres sedentárias e clinicamente saudáveis, durante a contração de agachamento convencional e associados à adução e à abdução isométrica da coxa com carga de 25% do peso corporal. A análise estatística empregada foi o modelo linear de efeitos mistos, com significância de 5%. **Resultados:** A associação da adução e abdução isométrica da coxa no agachamento produziu cerca de 0,47 (0,2) e 0,59 (0,22), respectivamente, de atividade elétrica do músculo GMed, enquanto o agachamento convencional (AGA) produziu 0,33 (0,27) de atividade elétrica. A maior ativação do VMO aconteceu na contração de agachamento associado à adução da coxa e foi de 0,59 (0,27); já o músculo VLL apresentou uma maior atividade elétrica durante o agachamento associado à abdução, sendo de 0,60 (0,32). **Conclusão:** O exercício de agachamento associado à adução da coxa promoveu uma maior ativação muscular do VMO, além de aumentar a atividade muscular do GMed.

**Palavras-chave:** terapia por exercício; cinesiologia aplicada; eletromiografia; joelho; quadril.

**Received:** 04/01/2010 – **Revised:** 20/09/2010 – **Accepted:** 10/02/2011

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## Introduction

Squat exercises are often prescribed in physiotherapy practice for several knee impairments because when properly administered, it promotes an increase in knee and pelvic muscles strenght[1-3]. In addition, this exercise in closed kinetic chain is an integral part of functional activities and these exercises are often related with pain in patient with anterior knee pain (AKP) such as sport practices and going up and down stairs[1].

Exercises in closed kinetic chain associated to isometric contractions of hip abductors generate a higher electrical activation of the gluteus medium muscle (GMed) in healthy subjects when compared to the exercises done in opened kinetic chain. Additionally, the bipodal squat produces a better pelvic stabilization when compared to the unipodal squat[4]. Furthermore, although the associations of isometric hip adduction and abduction have been reported to produce an increased activity of GMed during bipodal squats, the same has been found not to be true when considering unipodal squats.

The squat with the association of isometric contraction of hip adduction has been shown to promote values of electromyographic amplitude similar for the medial and lateral portions of the quadriceps. Therefore, this squat modality promotes a better balance of the patellofemoral joint in comparison to the conventional squat (CS)[6]. However, these studies[6] did not evaluate the pelvic musculature.

Understanding how squats can be performed in order to promote a higher activation of patella and hip stabilizers is relevant because in addition to the dynamic stability of the patella, weaknesses of pelvic stabilizer are related to patellofemoral dysfunction[7-11].

There is no description in the literature regarding the most efficient way to perform squat exercises in order to promote balanced activation of the dynamic stabilizers of the patella and a higher electrical activity of the pelvic stabilizers. This information will help provide scientific basis and justification for the prescription of squat exercise for patients with AKP or patellofemoral dysfunction.

In this context, the purpose of the present study was to compare the electromyographyc activity of the patella and hip stabilizers between the positions of conventional squat and squats associated with isometric contraction of hip adduction and abduction in subjects with no complaint of AKP. The hypothesis of the present study is that squat associated with isometric contractions of hip abduction generates an increase in the electromyographic activity of the patella stabilizers when compared to the conventional squats and squats with hip adduction.

## Methods

Fifteen sedentary women with no AKP complain were recruited through verbal invitation and participated in this study. Inclusion criteria were women that presented with a maximum of two clinical signals of misalignment in the lower limb[12], with no complains of AKP[13], and no history of orthopedic or neurological conditions, trauma or previous surgery of bones, muscles and joints of the lower limb or spine, since pain is the main complain associated to AKP. Exclusion criteria was complain of pain in any part of the lower limb and performance of any type of physical activity, recreational or sportive, twice or more frequently per week[6].

All of the participants were properly informed about the study procedures and signed a free informed consent approved by the Ethics Research Committee of the Clinical Hospital of the Medical School of Ribeirão Preto, Ribeirão Preto, SP, Brazil (protocol nº. HCFMRP 14102/2006).

The surface electromyographic signals were collected bilaterally from eight double-differentials active electrodes with three Ag/AgCl bars (dimensions 23x21x5 mm and distance between electrodes of 10 mm), with gain of 20x, input impedance of 10GΩ and band-pass filter and the common mode rejection ratio of the 130dB. The active electrodes were positioned on the *vastus medialis obliquus* (VMO), *vastus lateralis obliquus* (VLO), *vastus lateralis longus* (VLL) (Figure 1A)[14] and GMed (Figure 1B)[15]. They were fixed with a double-sided adhesive tape to the skin previously prepared and the connections were tested according to the rules of the *Surface EMG for Non Invasive Assessment of Muscles Project*[15]. The stainless steel ground electrode (diameter of 3 cm) was fixed to the sternum.

The signals were analogically amplified and digitalized with simultaneous frequency of sampling of 2 KHz by channel, in the range of 0.01–1.5 kHz, by the convertor board of 16 bits of resolution of dynamic range from the portable

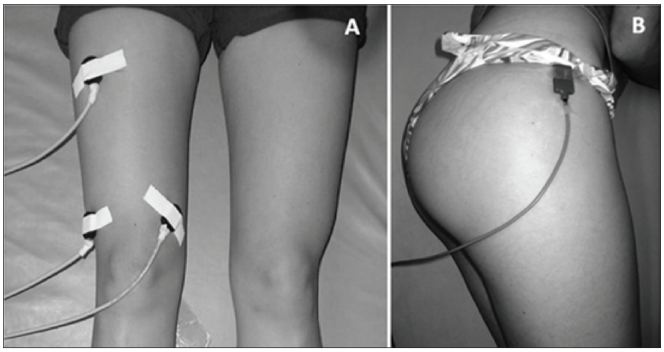


**Figure 1.** Sensors position on the vastus medialis obliquus, vastus lateralis obliquus and vastus lateralis longus according to Bevilaqua-Grossi et al.[14](1A), and gluteus medium according to SENIAM project[15](1B).

device *Myosystem BR-1P84*, from the brand *Datahominis* (Uberlândia, Minas Gerais, Brazil). The *Myosystem Program,* version 3.5, was used for visualizing and processing the electromyographic signal.

The electromygraphic signals of the VMO, VLO and VL were collected during three maximal isometric voluntary contractions (MIVC) of shank extension, with the knee fixed at 90° of flexion (extensor chair), since this position facilitates a higher electrical activity of the quadriceps muscles[1]. The MIVC of the GMed was collected in the manual muscle testing position[16]; with the hips in 20º of abduction and 10º of extension. Pelvic stabilization and the resistance imputed to the distal portion of the leg were applied manually by the same evaluator[17]. The MIVC of these activities were maintained for six seconds, and were later used as reference values for normalization of the electromygraphic data obtained in the squat exercises studied.

All isometric positions of squats were performed with an additional load of 25% of each subject body weight. This additional load was determined by trial and error, in a pilot study. This load was identified as the minimal capable load to intensify the myoelectric activity, especially of the muscle GMed, to an acceptable level of signal-noise relation using double-differential electrodes[9,14].

The electromygraphic data of the CS was collected with the participants with their back supported on a ball of 45 cm diameter, of the brand Carci®, and maintaining it against a wall, with 60° of knee flexion[18], feet apart and hips in neutral position of the frontal and transversal planes (Figure 2A). The squat exercises associated to the MIVC of hip adduction (CS-ADD)[6] were performed in the same position of the CS a support positioned between the legs, in the height of the medial femoral epicondyle (Figure 2B). The squat exercises with hip abduction (CS-ABD) were performed on the same position as the CS with addition of MIVC of hip abduction resisted by an non elastic band, adjustable with Velcro®, positioned leveled with lateral femoral epicondyle (Figure 2C). Pelvic movements in transversal and frontal planes were visually controlled by the evaluators. The squat contractions were recorded in isometric position to guarantee that the electromygraphic surfaces were not affected by the variations in tension-length and tension-velocity relation or even by the number of motor units active in the area of caption[19].

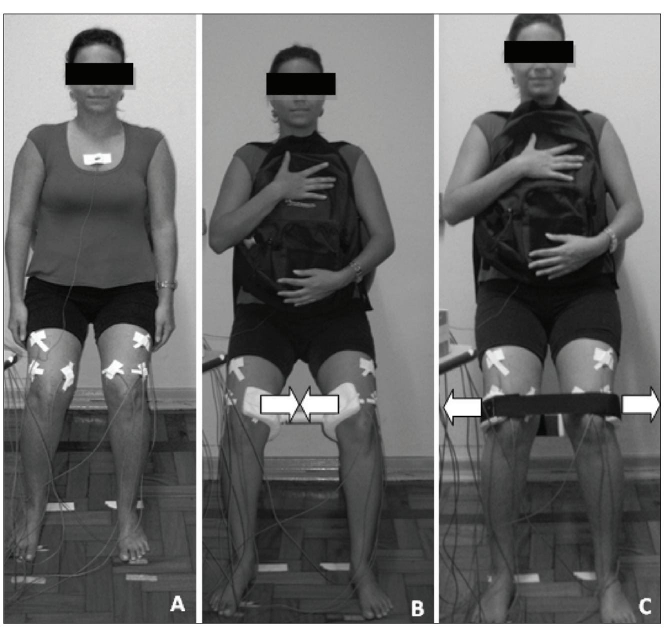

**Figure 2.** Traditional Squat with 60° of knee flexion and hip in neutral position (2A), squat associated with isometric contraction of hip adduction (2B) and quat associated with isometric contraction of hip abduction (2C).

The sequences of the exercises were determined by a simple draw and were recorded for six seconds of three contractions for each squats condition. All participants were verbally motivated during the contractions by the same examiner. A minimal resting time of two minutes between each contraction was established to minimize the effects of muscle fatigue[20].

The raw electromyographic signals were digitally filtered in the band of 20 to 500 Hz, and the root square of the mean squares (RMS, *root mean square*) was calculated to represent the amplitude of muscle activation.

The mean value of RMS of each muscle was normalized by the mean value of the RMS obtained in the contractions of reference of the same muscle[21]. In other words the RMS was normalized by the relation between the mean value of the studied contractions and the mean value obtained from the recordings of MIVCs. Thus, the values of amplitude of myoelectric activation are presented in arbitrary unit (AU). The muscle activity was characterized as minimal (between 0 and 0.39), moderate (between 0.40 and 0.74) and strong (between 0.75 and 1)[22].

Means and standard-deviations of the RMS normalized values were used to verify statistically significant differences between the dominant and non-dominant sides and between the different squat conditions. Mixed linear model[23] is a test of variance and was used in this study as it takes into account both the source of variations intra- and inter-subjects. This statistical method is recommended when the values of the same subject are grouped, and the assumption of independence between the observations in the group is not adequate[23]. The random effect was considered as being the muscles assessed, VMO, VLO, VLL and GMed, and the fixed effect was considered as being the exercises, CS, CS-ABD and CS- ADD.

The adjustment of the model for a normal distribution was done through the procedure PROC MIXED uinsg SAS® 9.0.

## Results

Demographic data and clinical parameters of sedentary women are presented on Table 1.

There were no statistical significant differences between the values of muscle activation of dominant and non dominant lower limbs. The associations both of hip adduction and abduction favored the activation of the muscle GMed (Table 2) in relation to the CS ($p<0.05$). In relation to the patellar stabilizers, the results showed that the VMO was more active in the squat associated with hip adduction in relation to the other squats tested ($p<0.05$). The VLL muscle, presented a higher electrical activity in the squat with hip adduction and abduction when compared to the CS ($p<0.05$) (Table 2). The comparison between the electromyographyic activities of the stabilizers of the patella did not show statistically significant differences.

## Discussion

The results of the present study revealed that the muscle activation produced by the proposed squats ranged between 26 and 60% of the activation achieved in the reference contractions, that were actually considered to be from weak to moderate[22]. The muscle GMed showed higher electrical activity in the squat with hip abduction or adduction when compared to conventional squat, which produced similar muscle activation for all of the muscles studied.

It is worth noting that even with the addition of a load equal to 25% of the body weight and the association of hip abduction or adduction the activation of the GMed in squat exercises were at most 59% of the amplitude generated at the reference position. Thus, when a muscle weakness is evidenced in the clinical assessment of patients, we must consider that the squat exercise, as proposed in this study may not be enough to improve the strength of these muscle and therefore, specific exercises may be included in the protocol.

Unlike the initial hypothesis, both the squat with hip adduction and the squat with hip abduction produced moderate activations that were larger than those achieved with the CS for the patella and pelvic stabilizer. However, despite all the squats presenting with balanced activity of the patella stabilizer muscles, the squat with hip adduction provided a larger electrical activity of the VMO compared to the CS-ABD. The contraction of GMed in these situations is due, probably, to its function as pelvic stabilizer and to the control of the internal rotation of the femur[24-26]. These data agree with the findings of Hertel et al.[5] that found that the addition of isometric contraction of hip adduction and abduction to unipodal squat have no effect on the electrical activity of GMed. However, despite the similarities of the result, the experimental conditions of the studies were different since in the present study volunteers kept both feet on the ground, had the back supported by a ball and had an added load of 25% of the body weight.

In addition to finding a moderate activation of GMed in squat contractions with hip adduction and abduction, the squat contraction with hip adduction provided greater activation of the electric

**Table 1.** Mean and Standard deviation of demographics and clinical parameters of the subjects (n=15).

| Parameters | |
|---|---|
| Age (years) | 22.26 (2.22) |
| Heigh (cm) | 161.7 (7.33) |
| Weight (Kg) | 56.56 (4.68) |
| Visual Analog Pain Scale (out of 100) – after squat (60 seconds of exercise) | 0 |
| Q-angle increase (%) | 14 |
| Excessive Subtalar Pronation (navicular drop test) (%) | 10 |
| Medialized Patella (%) | 100 |

**Table 2.** Mean and standard deviations of the normalized electromyographic amplitudes of the muscles: vastus medialis obliquus (VMO), vastus lateralis obliquus (VLO), vastus lateralis longus (VLL) and gluteus medium (GMed) during traditional squat (SQ), squat associated with isometric contraction of the hip abduction (SQ-ABD) and squat associated with isometric contraction of the hip adduction (SQ-ADD). Arbitrary Units (A.U.) (n=15).

| Dominant Limb | SQ | SQ-ABD | SQ-ADD |
|---|---|---|---|
| GMED | 0.33 (0.27) | 0.47 (0.20) [a] | 0.59 (0.22) [b] |
| VMO | 0.32 (0.12) | 0.52 (0.24) | 0.59 (0.27) [c] |
| VLO | 0.32 (0.12) | 0.38 (0.17) | 0.41 (0.11) |
| VLL | 0.37 (0.14) | 0.60 (0.32) [a] | 0.53 (0.16) [b] |
| Non-dominat Limb | | | |
| GMED | 0.26 (0.13) | 0.52 (0.24) [a] | 0.59 (0.27) [b] |
| VMO | 0.46 (0.33) | 0.38 (0.25) | 0.58 (0.59) [c] |
| VLO | 0.35 (0.14) | 0.37 (0.15) | 0.44 (0.15) |
| VLL | 0.49 (0.19) | 0.53 (0.19) | 0.61 (0.28) |

[a] Significant difference between SQ-ABD and SQ *p<0.05;* [b] Significant difference between SQ-ADD and SQ *p<0.05*; [c] Significant difference between SQ-ADD and SQ-ABD *p<0.05*.

VMO muscle, which are desirable activations in the rehabilitation of meniscal[27] and ligament[28] of the knee and in the AKP[29,30].

Moreover, the results of this study revealed that squat with hip abduction stimulated the activation of the GMed but also provided higher activity of the VLL. This greater activation of the VLL should not be advocated in the intervention of patellar dislocations and patellofemoral dysfunctions, since it could favor the lateralization of the patella[1].

Coqueiro et al.[6] reported that the prescription of exercises that promote muscle synergism of the patella lateral stabilizer musculature are as important as promoting the contraction of the medial portion of the quadriceps. Our data do not differ with regards to the activation of GMed and indicate a balanced activity between the stabilizers of the patella in the exercises CS-ADD and CS-ABD, but the squat exercise associated with adduction of the hip showed an increase in the myoelectric activity of the muscle VMO. It is suggested, therefore, that this exercise is the most suitable in the rehabilitation of patients with AKP, since it emphasizes the GMed activation and the activity of VMO.

The results of this study are limited by the lack of information about the kinematics of the pelvis and lower limb segments and the exact change of the patella positioning caused by the muscle contractions proposed. Another aspect that was not addressed is the relationship between the muscle *tensor fasciae latae* and its function of pelvic stabilizer together with the hip abductors muscles. Furthermore, the *tensor fasciae latae* muscle is an anterior-lateral stabilizer of the knee, and a weakness in this musculature can lead to increased shear forces and hence an increase in patellofemoral stress[31].

Finally, it is important to consider that this is an exploratory study and its results, as the variance of the average EMG amplitude, can be used as a basis for further studies that seek to replicate this method with a larger number of participants, as well as with AKP patients, highlighting the therapeutic value of these exercises.

## Conclusion

The results of this study showed that the squat exercise associated with hip adduction produced higher activation of the VMO muscle, and produced an increase in the activity of the GMed.

## Acknowledgements

To the Fundação de Amparo à Pesquisa do Estado de São Paulo - FAPESP (process number 2007/08461-6), for the financial support, and to the Center of Quantitative Methods- CEMEQ/Clinical Hospital, FMRP, for the statistical analysis

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